AAMRL-TR-89-008

CONFERENCE ON OCCUPATIONAL HEALTH ASPECTS OF ADVANCED COMPOSITE TECHNOLOGY IN THE AEROSPACE INDUSTRY

VOLUME I. EXECUTIVE SUMMARY

MARCH 1989

EXECUTIVE SUMMARY FOR THE PERIOD 5-9 FEBRUARY 1989

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HUMAN SYSTEMS DIVISION
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TECHNICAL REVIEW AND APPROVAL

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Volume I

This summary represents the statements and opinions of the participants and does not necessarily reflect the policy or position of the Department of Defense and the separate services, the Suppliers of Advanced Composite Materials Association (SACMA), the Aerospace Industries Association (AIA), or the member companies of these organizations.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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The U.S. Air Force sponsored a national conference on the Occupational Health Aspects of Advanced Composite Materials in the Aerospace Industry, 6-9 February 1989, in Dayton, Ohio. The conference was developed in cooperation with the Suppliers of Advanced Composite Materials Association (SACMA) and the Aerospace Industries Association (AIA). It was attended by over 230 representatives from the Department of Defense and the Service Components, industry, labor, and other Federal agencies.

The goals of the conference were to promote technology transfer and to provide a forum for discussion to determine:
- a) What is known and, possibly more importantly, what is not known about the health effects of composites.
- b) Availability and effectiveness of current controls in preventing worker illness.
- c) The need for epidemiologic studies on the health effects of composite materials.
- d) The availability of health information to the worker in the form of training and hazard communication.

The overall conclusion is that while there are some health problems associated with the use of these materials, the problems are neither unique to these materials nor the aerospace industry, and the problems are solvable with current technology.

The report on the conference is provided in two volumes. Volume I: Executive Summary includes summaries of the major issues addressed by the conference along with abstracts of the technical presentations. Volume II: Proceedings provides the full text of the presentations. Keywords:

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PREFACE

A conference on Occupational Health Aspects of Advanced Composite Technology in the Aerospace Industry was held in Dayton, Ohio , on 6-9 February 1989. The Air Force Systems Command's Human Systems Division, Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL) hosted the conference which was sponsored by the Department of the Air Force with the cooperation of the Suppliers of Advanced Composite Materials Association (SACMA) and the Aerospace Industries Association (AIA). Coordination of the conference was provided by NSI Technology Services Corporation, under the terms of Contract No. F33615-85-C-0532 with the Air Force. LtCol Harvey J. Clewell served as the Contract Technical Monitor.

LtCol Michael B. Ballinger, AAMRL/TH, served as the Conference Chairman, and Patsy J. Gergely served as the Conference Administrator. The Session Coordinators were: LtCol Michael B. Ballinger (Perspectives and Expectations), Dr David R. Mattie (Technology Overview), Major Robert G. Elves (Health Effects and Exposure Considerations), CDR David A. Macys (Engineering Controls and Work Practices), LtCol William D. Gould (Occupational Medicine Considerations), LtCol Edward C. Bishop (Hazard Evaluation and Communication), and LtCol Harvey J. Clewell (Needs Review and Action Agenda). Lois A. Doncaster was the Conference Coordinator for NSI Technology Services Corporation, which provided administrative support for the conference. This report was prepared with the technical and editorial assistance of Battelle. In particular, Keith J. Johanns and Barbara S. Bechtel provided key support during the preparation of the consensus statements and summary.

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I. CONFERENCE SUMMARY

The U.S. Air Force sponsored a national conference on the Occupational Health Aspects of Advanced Composite Materials in the Aerospace Industry, 6-9 February 1989, in Dayton, Ohio. The conference was developed in cooperation with the Suppliers of Advanced Composite Materials Association (SACMA) and the Aerospace Industries Association (AIA). It was attended by over 230 representatives from the Department of Defense and the Service Components, industry, labor, and other Federal agencies.

The goals of the conference were to promote technology transfer and to provide a forum for discussion to determine:

- What is known and, possibly more importantly, what is not known, about the health effects of composites.

- Availability and effectiveness of current controls in preventing worker illnesses.

- The need for epidemiologic studies on the health effects of composite materials.

- The availability of health information to the worker in the form of training and hazard communication.

The overall conclusion is that while there are some health problems associated with the use of these materials, the problems are neither unique to these materials nor the aerospace industry, and the problems are solvable with current technology.

The following section summarizes the major issues addressed by the conference and was prepared by the summary working group listed at the end of the section. A more complete discussion of the specific topics addressed by each of the conference technical sessions is provided in Section II. These consensus statements were prepared by the coordinator and speakers of each technical session. Abstracts of the individual technical papers presented at the conference are contained in Section III.

- **Advanced Composites Are Critical To National Defense.**

Advanced composites were first introduced in the late 60's and early 70's on the F-111, F-14, F-15, and F-16. Since that time the technology has matured to where 40-60% of the next generation fighter and attack aircraft will be made of composite structures. The superior specific strength, specific stiffness, and fatigue resistance offered by advanced composites produce increased performance at reduced weight. The increased capabilities they give our aircraft make composites critical to national defense.

- **The Use Of Composites Is Rapidly Increasing.**

Virtually every airframe being designed today is using advanced composites for a portion of its structure. This is true for commercial as well as military aircraft, domestic as well as foreign aircraft. The explosion in the use of this technology is leading to dramatic increases in the quantity of advanced composites processed every year. One domestic airframe company expects to increase its use of composite material in the next decade from 100,000 pounds to over 1,000,000 pounds annually.

- **The Worker Is The Most Important Asset.**

Employers must convince their workers that they are concerned for their workers' welfare and allow the workers to be involved in ensuring a safe working environment. Employees must not only be protected, but also feel protected.

- **The Availability And Quality Of Material Safety Data Sheets (MSDS) Need Improvement.**

The MSDS is the primary source for transmitting hazardous material information from the initial supplier to the worker. Although the supplier is required by the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (HCS) to supply the MSDS to the user, OSHA enforcement of the HCS effectively shifts the burden of obtaining the MSDS to the user. This requires the user to establish administrative mechanisms to ensure the MSDS is available to the worker.

Quality of MSDS information is also a major issue. There is a large degree of variability in the quality and format of information from various manufacturers. Often this information is written in highly technical language which is not readily understood by the target audience, the worker.

- **Medical Monitoring Is A Component Of An Effective Occupational Medicine Program.**

Medical monitoring is an important tool to provide early identification and prevention of occupational illness. Available technological advances offer new levels of effectiveness, but the rapid proliferation of industrial chemicals challenges medical analytical capabilities.

- **Occupational Health Considerations Must Be An Integral Part Of The Design And Manufacturing Process.**

Health and safety professionals must be involved at the initial stage of product development. Their involvement must continue through the entire process of production, marketing, and use. Toxicity assessments and the development of exposure control measures and medical surveillance protocols based on these assessments can progress in parallel with industrial research and development. This will help ensure the information needed by manufacturers and users will be available at the time of product introduction. This proactive "system safety engineering" approach involving supplier, manufacturer, and user health and safety professionals will ensure good control of potential health effects, and will also minimize the impact of controls on production.

- **Technological Advances In Advanced Composite Materials Have Outpaced The Health Issues.**

Although the rapid development of these materials has not always allowed health issues to keep pace with the introduction of new composite systems, there is an underlying awareness of the potential health hazards associated with these materials. The rapid evolution and turnaround of resin matrix systems requiring long-term toxicological studies makes the health hazard evaluation of individual resin systems infeasible. Rather, the hazards associated with individual components of a given resin matrix system have been, and should continue to be, evaluated and used to develop employee health protection.

- **Engineering Controls Are Generally Available And Need To Be Consistently Applied.**

The technology required to control potential hazards that may be associated with composites is generally well understood, available, feasible, and effective. Proper implementation of the controls, however, is key to effective hazard control. Where chemical hazard and toxicologic information is unknown or sketchy, there is a consensus among health professionals that the controls used must be based upon a conservative approach to maximize worker protection. Controls are inconsistently applied in the composites industry. Diversity is seen both in the choice of controls and the effectiveness of the controls used.

- **Personal Protective Equipment Is Frequently Required To Supplement Or Temporarily Replace Engineering Controls.**

Personal protective equipment, while generally available, is not always satisfactory. Issues identified include worker acceptance, impacts on product quality and production rate, lack of uniform performance standards, and inability to make safety or economic changes due to Federal Agency certification requirements. These problems are compounded when inadequate information on the specific hazards is available.

- **Engineering Controls And Work Practices For Repair Are Different For Depot- And Field-Level Repairs.**

The engineering controls and work practices for repairing advanced composite structures at the depot-level are very similar to those that would be found in a manufacturing facility. For field-level repair, however, it is unclear to what extent engineering controls can or must be used. Work practices will probably continue to rely heavily on personal protective equipment.

- **Fibers From Advanced Composites Are Of Minimal Health Risk.**

The health concerns of raw reinforcement fibers are minimal. Numerous studies of these fibers have indicated that they do not pose an asbestos-type hazard.

- **The Health Risk From Composite Material Dust Is Less Well Characterized.**

The health effects of dust generated from machining cured composites are less understood. Preliminary studies indicate that the dusts have very few fibers of respirable size. The particles may be capable of producing a lung response greater than that from "nuisance" dusts but far less than that from quartz dust. The dust may also include uncured matrix material which could increase the health risk.

- **Dermal Contact Is A Significant Route Of Exposure.**

Dermal exposures are considered to be an important problem to address because exposure to the skin may be significant. It is, however, more difficult to evaluate and quantify than inhalation exposures. There is also confusion about the appropriate type of glove or barrier cream which will provide both protection and the required tactile sensitivity. Hand protection must not introduce contaminants into the product which may affect the quality.

- **Odor And Discomfort Complaints Should Be Taken Seriously.**

Even though workers may not be experiencing a direct toxic effect due to exposure, complaints of odor and discomfort must be taken seriously. These complaints indicate concerns which, if left unaddressed, in the absence of sufficient health information may become a more serious problem.

- **Illness May Be Exacerbated By Misinformation.**

Any adverse health effect related to chemical exposure may be significantly exacerbated by misinformation from health care providers, news media, and poor communication between labor and management.

- **Antibody Testing May Not Correlate With Clinical Disease.**

Testing for antibodies to formaldehyde and most other reactive chemicals currently does not correlate with chemical exposure and chemical disease. Such antibody testing should be performed only as part of a well-controlled epidemiologic study.

- **Epidemiologic Investigation Should Be Carefully Considered.**

Epidemiologic investigation of potential health effects of composite materials, such as immunological or neuropsychological dysfunction, should be carefully considered, realizing the inherent limitations of such studies. These limitations include the potential for bias, the difficulty of classifying exposure in a multi-chemical environment, the lack of animal data demonstrating a causal link to a specific adverse effect, and the limited sample sizes of the exposed cohorts.

- **The Cooperative Spirit Fostered By This Conference Should Be Actively Maintained.**

One of the most notable results of this gathering has been the formation of more extensive ties among the representatives of the various government agencies, industries, and labor. Maintenance of these relationships will go a long way toward ensuring the rapid and effective transfer of information as well as preventing duplication of effort. The continued preservation of the safety and health of aerospace workers can best be assured through a common commitment to a coordinated proactive program.

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II. TECHNICAL SESSION CONSENSUS STATEMENTS

Composite Technology Overview

This session reviewed advanced organic polymer matrix resins and continuous high strength, high stiffness fibers to develop a common understanding of advanced composites. Areas addressed were applications, materials manufacturing and use of composite parts in aircraft, manufacturing, supportability, and future advanced composite materials.

Polymer matrix composites are materials made from two distinct phases - an organic polymer resin binder or matrix and a continuous fiber used as reinforcement to achieve properties not otherwise attainable. The strength and stiffness characteristics are equivalent or superior to aluminum, the metal with the highest strength to weight ratio. There are a number of resin systems used today in combination with such fibers as boron, glass, aramid, and carbon or graphite.

The use of composite materials over time has increased dramatically. The percentage of airframe structural weight made of composites for military aircraft has risen from the 3-5% level for F-14, F-15, and F-16 aircraft in the late '60s and '70s, to 27% for the AV-8B, with projections of 40-60% for emerging aircraft such as ATF and ATA. The usage of composites at one aircraft manufacturer alone is expected to increase during the next decade from the current level of about 100,000 pounds to over 1,000,000 pounds annually.

Polymer matrix resins and their prepregs are chemically reactive systems by design. The unreacted materials present a variety of potential hazards to those who work with them. The degree and the scope of the hazard depend significantly on the particular resin system and how it is handled. There is a diversity of forms, processes, and raw materials. How materials are combined and how materials are normally handled in the workplace were reviewed. There are various polymer matrix resin systems that are currently based on epoxy compounds, polyesters, phenolics, silicones, and polyimides such as bismaleimides (BMIs).

Part-forming processes also are numerous and range from high worker-contact hand layup to automated tape-laying machines that reduce worker contact with reactive resins. Although many automated or semi-automated forming processes (such as filament winding, machine tape laying, braiding, and pultrusion) are available, hand-lay operations are still quite common in the industry. The F-16 was used as an example to illustrate several applications of the three main steps in manufacturing using composites, and the interaction of the human element in each step. Layup (the placement of composite material onto the part mold) was demonstrated by showing the fabrication of stabilizer skins and fiber glass covers. Processing or curing (the application of heat and pressure to consolidate the laminate and cross-link the matrix) was illustrated with autoclave, press, and oven operations. Machining (drilling, trimming, and routing of the processed laminate) was demonstrated by showing the assembly of stabilizer skins.

With extensive expansion of applications and usage, worker exposure to composite materials will increase at all levels of operations, even with current automated processes. Exposures will occur in laboratories due to material sampling, inspection, and receiving testing. In the manufacturing shop, exposures will increase due to the larger sizes of composite parts, greater number of material rolls or containers, and increased number of parts to be handled and/or observed. Ultimately, new automated and non-automated robotic processes will be necessary, not only for increased productivity and cost savings, but also for the health safety of the worker by minimizing exposure.

Supportability of advanced composite structures was addressed using examples from McClellan AFB. Supportability is a tremendously broad subject. It includes everything from the basic design concept of the structure, to how that particular structure meshes with other structures in the weapon system. Supportability also involves the specific materials used in manufacture, technical data, repair methods, training, and the personnel and support equipment required to keep that structure functional.

The future offers many unique opportunities for the development of higher performance composites. Epoxies, including new phase toughened resins, will be most widely used; but polyimides and BMI's will continue to increase their percentage of the market. Thermoplastic resins will continue to grow in usage as improved manufacturing methods and better materials evolve. As part of the Air Force's Project Forecast II, new technology efforts are being pursued to support the development of ultra-lightweight composite aircraft that are 50% lighter than current high performance aircraft. This will require a combination of new materials technologies, with the principal focus being on higher performance reinforcing fibers. Ordered polymer and molecular composite technologies will also be pursued.

Questions Asked:

Although waste disposal of composite materials is not perceived as a problem, it was felt by several individuals that this area needs to be examined further. If this is a problem, a subset of this issue is how to handle the disposal of hazardous materials which may also require demilitarization prior to disposal. Training questions asked were threefold:

1) How does the Air Force train its people to do composite repair and maintenance?

2) What worker safety training programs are in place at manufacturing plants (chemical producers, composite suppliers and users)?

3) Should training on safe handling and protection be part of the MSDS?

This last question is tied to the need for information regarding the chemicals used. It is a challenge trying to balance the safety needs of the customers and their employees with the need for security to protect proprietary materials.

Health Effects and Exposure Considerations of Advanced Composites

The toxicology and industrial hygiene issues associated with advanced composite components and matrices are those of complex mixtures. These health issues aren't unique to the advanced composite industry. Intelligent assessments of human health hazards of complex chemical mixtures are made, despite the paucity of data on such mixtures, throughout the chemical industry. These hazard assessments are made by integrating information on the inherent toxicity of the various components in such complex mixtures with data on exposure to the mixture.

Because of the rapid evolution and turnaround of resin matrix systems and toxicological studies requiring years, evaluation of individual resin systems isn't feasible. Rather, the hazards associated with individual components of a given resin matrix system have been and should continue to be evaluated. The individual component data should be combined into an averaged hazard assessment. Such an assessment is based on known effects of these components and sound scientific judgment. The establishment of exposure standards for complex mixtures will be dependent on validation of current techniques and models of exposure.

Polymer matrix resin systems are chemically diverse and reactive systems by design. Therefore, the uncured materials present a variety of potential health hazards. The degree and scope of the hazard is dependent on the particular resin system used.

Exposures to mixtures of gases, vapors, and liquids, as well as man-made fibers and particles, are possible during various composite operations.

Approximately one-half of composite matrix systems contain epoxy based resins. Most forms of unreacted epoxy resins have a low order of acute toxicity and aren't readily absorbed. Epoxy resins may produce skin irritation or sensitization.

Other resin systems of importance include the polyurethanes and urea- and phenol-formaldehyde resins (U/F and P/F). The isocyanate component of uncured urethane resins and formaldehyde in the U/F and P/F resins present hazards to the worker both in terms of acute toxicity and potential chronic effects. In addition, the minor additives must be considered since many are skin irritants and sensitizers and may be potentially carcinogenic or teratogenic. Precautionary action should be taken to avoid all skin contact with uncured resin systems. Owing to their sticky nature, resins on the skin are difficult to remove, and workers shouldn't use solvents to remove them because they facilitate skin penetration of the resin systems. In general, most unreacted resin systems may also cause eye and respiratory irritation.

Relative to raw fiber production, numerous studies on carbon, graphite, fiber glass, and aramid fibers have indicated that in general, most reinforcement fibers have diameters outside the respirable range. Those which are respirable have low airborne concentrations and low order of toxicity permitting their use in composite manufacturing operations without undue health risk to workers. Exposure to reinforcement fibers may cause mechanical irritation of the eyes, nose, and throat.

Composite dusts are primarily composed of cured binder with relatively low concentrations of free fibers. Preliminary studies indicate these dusts are capable of producing lung insult greater than "nuisance dust" but far less than quartz dust. Therefore, treating these dusts as "nuisance dusts" may be inappropriate. In general, cured resin dusts from composite reworking may cause eye and respiratory irritation.

In certain cases, monitoring techniques can be employed to measure exposure to composites materials. Surface contamination testing, biological monitoring, and product analysis all produce information which may be useful in a hazard assessment.

In developing recommended exposure limits, factors to be considered include 1) identification of the material, contaminant, or decomposition product causing the adverse health effect; 2) type of work, processes used, and demographic characteristics; 3) quantitative personal exposure measurements; and 4) the health outcome being studied and its time relationships with the presumed harmful exposure.

Recommendations:

Since some fibers can absorb contaminant chemicals, future studies should assess this situation along with the pyrolysis products of composite matrices.

Future research in these areas of development and use of innovative monitoring methods, worker health surveillance, toxicity testing, and chemical dermal penetration measurements will provide useful information to health professionals performing composite material exposure evaluations.

A specific national defining criteria for the hazards associated with composite components should be established. The American National Standards Institute (ANSI) publishes a standard entitled "American National Standards Guide for Classifying and Labeling Epoxy Products According to their Hazards Potentiality". The intent of this standard is to provide producers and distributors of epoxy resins and related products with classification criteria and labeling recommendations so they can better define the hazard categories into which their specific products fall and design labels that will warn the buyer and user of any hazards that exist. The resin system additives aren't specifically covered in the scope of the ANSI guide; however, the same criteria for assignment can be used to rate them on a comparable basis.

Engineering Controls and Work Practices

The purpose of engineering controls and work practices is to control exposures to prevent adverse effects. For the purposes of this analysis, exposures can be categorized as occurring either in the manufacturing and production industries, or as the result of maintenance and repair functions. These latter can be further subdivided into depot-level, intermediate-level, and field operations.

Based on many years of operational experience, the knowledge exists to properly design both facilities and equipment to either isolate or contain toxic materials, or to minimize exposures to them. When properly maintained and used as designed, these facilities and equipment do indeed adequately control exposures since adverse effects are infrequently reported.

At the depot level, conditions are generally similar to but on a smaller scale than those in the manufacturing and production facilities. The conclusions drawn above apply. At the intermediate and field levels, however, it is unclear to what extent engineering controls can be used and with what degree of success.

Needs and Concerns:

New technology (automated materials handling, robotics) for containing or isolating many operations offers the potential for eliminating many exposures; however, this is also very expensive technology. Initiatives to reduce the cost of such equipment are needed.

Much innovative work has been done to control exposures using engineering controls in the complex and idiosyncratic operating environments of the composites' manufacturing and production industries. Most of this work is not generally known outside the company which sponsored and uses it, yet it may well have wider applicability. The ACGIH Industrial Ventilation Manual or other widely recognized resource should be used to disseminate this information.

Two forms of periodic monitoring are required to ensure engineering controls are and remain adequate. The first is industrial hygiene monitoring of exposure levels to ensure the equipment is performing as intended. Exposure levels found by such monitoring should be considered in a manner similar to the ventilation designs mentioned in the previous paragraph, and treated analogously. The second is medical monitoring of exposed personnel to ensure that their exposure is not causing any adverse effects. This topic is dealt with elsewhere in more detail.

Work Practices:

Requirements for work practices necessary to supplement engineering controls, or to substitute for engineering controls when those are not practical, have been identified and implemented. Experience has validated their efficacy when implemented as an integrated program based on job hazard analysis, and when used properly and conscientiously. Included are personal protective equipment, housekeeping, employee feedback opportunities, labeling, and process specifications (not an exhaustive list). An integral part of a successful work practices program is thorough employee training and routine hazard communication, addressed elsewhere in this document in more detail.

While the same work practices remain valid in general, their ability to replace engineering controls in providing adequate exposure control when those are not available remains in doubt. This is likely to be a significant problem at the intermediate and field maintenance levels. The depot-level should function sufficiently similarly to manufacturing and production facilities that the same solutions will be equally applicable.

Personal protective equipment, while generally adequate, is not always satisfactory. Gloves are a good example of the nature of the problem. Many manufacturers make protective gloves of various materials to resist penetration by different chemicals. Review of their literature reveals significant variability in their claims for resistance -- for what is supposedly the same material. No standardization exists, or even guidelines for standardized testing. It is proposed that the composites' industry develop a set of requirements or specifications for protective gloves, and an estimate of the potential market for such gloves, and approach the glove manufacturers to determine whether this would warrant their making available such a glove.

A related factor is the difficulty in selecting the appropriate work practices (e.g., personal protective equipment, training) for a given material in a specific operational environment. This is complicated by the frequently inadequate information provided on many MSDSs. While this is dealt with in detail elsewhere, its impact on this topic bears repeating here.

The need for periodic monitoring of the effectiveness of engineering controls described earlier is also relevant for ensuring the effectiveness of work practices. Further data regarding work practice effectiveness should be treated similarly.

Emergency Preparedness:

Emergency situations are created when (1) the failure of equipment or work practices results in the sudden, unexpected release of toxic material into the work area, or (2) a runaway exothermic reaction, fire, and/or crash releases thermal decomposition products and fibers into the environment. Procedures to control such events, and the attendant personnel exposures, have been implemented to varying degrees throughout both the manufacturing and production industries and in maintenance and repair activities. These include written SOPs, appropriate training, periodic drilling, and ready availability of emergency response equipment (including frequent inspection and maintenance).

Emergency situations involve the potential for exposure to a complex mixture of materials whose composition, concentration, and toxicity (either singly or as part of a mixture) are not clearly defined. In the absence of such data, the highest degree of protection (e.g., use of SCBA vice negative pressure respirators) is required. The causes of such events must be identified and minimized. Appropriateness of procedures and protective measures must be evaluated by hazard analysis, with periodic review as new toxicological data becomes available.

Occupational Medicine Considerations

A principal role of Occupational Medicine (OM) in the advanced composite industry is to carefully evaluate workers who have been exposed to composite materials. OM's role is not unique to composite industry but encompasses all aspects of research and development, manufacturing, and user industries.

Most of the well-established general problems of resins, hardeners, and solvents also exist with those that have composite applications; e.g., irritant and allergic dermatitis and sensory and mucous membrane irritation.

Industrial hygiene information to date indicates that composite fibers are not of a size to penetrate deeply into the lung or pose a cancer hazard. Nevertheless, potential respiratory effects should be addressed as part of medical monitoring.

Episodic exposure of greater than normal intensity to composite materials (fire, spills, resin exotherm) may occur and should be medically evaluated. These exposures should be further investigated for potential linkage to the recently described reactive airways dysfunction syndrome (RADS) (mild asthma).

Antibody levels and other immune system testing currently do not correlate with exposure or clinical illness and should be performed only as a part of a well-controlled epidemiological study.

Methylenedianiline (MDA) is a particular concern in OM. Animal data and anecdotal human data implicate this substance as a liver toxin. It is a known animal and "suspect" human carcinogen. Medical monitoring with liver function tests (LFTs) is necessary for the most frequently exposed worker. Measurement of MDA in body fluids in this case appears to be feasible and needs to be explored. Other chemicals may also require medical monitoring, but good methods have not been adequately developed.

Phenol-formaldehyde is one of the most frequently encountered resins in industry today. Laboratory testing for serum antibodies to formaldehyde is not useful for individual employee monitoring due to the lack of a clear understanding of its significance. Medical monitoring of employees exposed to phenol-formaldehyde resins should be performed. Monitoring for formaldehyde, phenol, or their metabolites is currently not useful.

An unresolved key issue is the combination of extrinsic and/or intrinsic psycho-social stressors (long work hours, cancer-phobia, misinformation from health care providers, labor-management friction, media hype) with low-level workplace irritants (odors, respiratory irritants). This combination may result in a "crisis of concern" which makes objective study of the issue impractical. When this results in anxiety and depressive disorders, the accompanying nonspecific symptoms create an extremely confusing clinical picture.

It is not clear whether the high prevalence of anxiety and depression seen in some composite workers is due to very low-level chemical exposure associated with sensory irritation of the respiratory tract. It is possible that sociological factors (such as fear, distrust, misinformation from health care providers, group interaction, attorney and/or media involvement, or labor-management problems) are playing a major role in producing or exacerbating these workers' symptoms. To address this concern, it is necessary to study the prevalence of anxiety and depression in a similarly exposed group of workers and matched controls in workplaces that are not "contaminated" by these other sociologic factors. Carefully designed epidemiological studies are needed if one is to address the influence of such sociologic factors.

Recommendations:

Medical monitoring should encompass the establishment of an employee baseline exam and incorporate the acquisition and review of periodic medical evaluation data. The function of such monitoring as a tool to provide early identification and prevention of occupational illness currently has technical limitations; nevertheless, such monitoring for workers engaged in composite fabrication and/or rework can be clinically useful and serves to establish a good relationship with the worker and promote early contact when problems do arise.

While medical monitoring is a very valuable tool, the primary method of preventing occupational illness in the composite industry should be the control of chemical exposures in the workplace using good industrial hygiene practice such as:

a. Substitution of selected chemicals with less toxic substances.

b. Engineering controls such as process enclosures and local exhaust ventilation.

c. Administrative controls such as limiting exposure time.

d. Use of personal protective equipment for the eyes, skin, and respiratory system.

e. Employee education and training.

Health and safety professionals must be involved in impact analysis for any new or unfamiliar chemical at the research and concept stages rather than just the manufacturing or post-manufacturing stages. Toxicity assessments, industrial hygiene measures, and medical monitoring protocols can thus progress in parallel with industrial research and development.

Hazard Evaluation and Communication

A conference goal was to determine whether or not epidemiologic studies of composite workers are needed and, if so, under what conditions. It appears that epidemiologic studies are not appropriate at this time because the causative agents have not been well defined due to multi-chemical exposures, insufficient number of controlled animal experiments, and undefined adverse effects. Considering these limitations, epidemiological studies will probably be extremely expensive and unproductive in determining a cause-effect relationship with composite chemical exposure.

When epidemiologic studies are feasible it must be realized that much larger study populations are required to prove a chemical safe than to prove it is a hazard with the same degree of statistical confidence. The study group size effect is much greater when the disease outcome is extremely rare. Additionally, it must be accepted that exposure indices derived from work history information may be misleading and could bias the study toward finding no effect.

Material Safety Data Sheets (MSDSs) are the primary source for transmitting hazardous material information from the initial manufacturer through the distributors to the final receiver - the worker. MSDSs were not required for *hazardous materials for any* industries except shipyards until the beginning of the 1980's, although many companies provided MSDSs due to customer demand. The Occupational Safety and Health Administration Hazard Communication Standard, 29 CFR 1910.1200, now requires MSDS in the workplace for all hazardous materials in all industries.

There are a variety of MSDSs, from the two-page OSHA Form 174 to 10-20 page formats. Although an MSDS must be automatically shipped with the first shipment of hazardous materials and whenever the MSDS is updated, enforcement of the OSHA HCS places the burden of obtaining the MSDS on the hazardous material user. This requires the user to establish administrative controls to ensure MSDSs are received.

Quality in MSDSs is a major issue. Often the information appears to be provided strictly to limit the manufacturer's liability. For example, suggested personnel protective equipment is usually the maximum available, regardless of the degree of toxicity of the product. There is a large degree of variability in the quality of MSDSs, which may be due to some extent to the size of the company preparing the MSDS. For example, smaller companies don't always have familiarity with the references in 29 CFR 1910.1200 and may not have the ability to conduct required testing.

Proprietary information or trade secret information is protected from disclosure; however, to be protected, a trade secret must meet the following criteria:

a. Not previously disclosed.

b. Not required by federal law.

c. Substantial competitive advantage.

d. Not readily discoverable by reverse engineering.

However, trade secret information must be available to health professionals in the event of a medical emergency, or if the information is needed to protect the health of the worker. The health professional may be required to sign a statement of nondisclosure.

Labeling may be the first contact the worker has with a hazardous material. The label must have a name linking it to an MSDS. It must tell the hazard and not be merely a precautionary statement such as "Do not breathe the vapors." The label must also include the name and address of the responsible party. This last requirement is not necessary for inplant labeling systems. Labels should be concise. Lengthy labels are less likely to be read and followed.

Workers want to perform their job without getting sick. They want full information on the chemicals with which they are working, the type of personnel protective equipment required, and the type and degree of engineering controls available. If the hazards are not known, the worker must be fully protected until the degree of hazard is defined.

The worker must receive this information through hazard-specific training. Workers desire to actively participate in the development and presentation of the training program and the design of workplace controls. This training must be completed and the engineering controls must be in place before employees begin work with the material. Workers also want their complaints taken seriously and to be involved in the selection of doctors.

An effective hazard communication training program contains the following elements:

a. An enthusiastic instructor who is familiar with the work area.

b. Presentation to small groups (less than 20), including the first line supervisor.

c. Encourage questions.

d. Use product handling information sheets which discuss work area specific work practices, personnel protective equipment, engineering controls, any special handling procedures such as maximum temperature, carcinogen designation if appropriate, the phone number of the preparing individual, and the location of additional information.

e. A feedback loop where the trainer visits the employees to determine the effectiveness of the training.

f. An occupational health staff which is willing and available to listen.

In summary, effective occupational health programs are distinguished by good communications between management and the employee which convey management's genuine concern for the employee. *One indicator of this concern is a* strong, visible occupational safety and health program which participates in the management process and is able to initiate actions to correct poor work facilities and practices.

III. ABSTRACTS OF TECHNICAL PRESENTATIONS

Composite Technology Overview

Earl Turns, Lee McKague, and B.G.W. Yee
General Dynamics, Fort Worth Division

Many trade journals and industry news services have long been predicting and reporting an exponential growth in the application and use of composite materials. This has been graphically reflected as percentage of airframe structural weight made of composites over time for military airplanes. This percentage has risen from the 3-5% level for F-14, F-15, and F-16 aircraft in the late '60s to '70s up to 30-50% for emerging aircraft such as ATF, ATA, and B-2.

The F-16 itself provides an example of this expanded usage. As originally designed in the mid '70s, only about 3% of the structure was made of advanced composites. These applications were to the skins of the empennage, where graphite-epoxy is used. Today, a new model of the F-16 – the Agile Falcon F-16 – is being planned for production in the 1990's; and it will have about 20% of its structure made of composites. In addition to empennage skins, wing skins, access doors, stiffeners, and other structural members will be made of composites.

As a result of these new applications and similar ones on all new aircraft programs, annual usage of composites at GD/FW is expected to increase during the next decade from the current level of about 100,000 pounds to over 1,000,000 pounds annually.

Many materials and material forms are involved in this expansion. Thermoset resins will continue to be widely used with graphite fibers. Epoxies, including new phase toughened resins, will be most widely used; but BMI's and polyimides will continue to increase their percentage of the market. Thermoplastic resins will continue to grow in usage as improved manufacturing methods and better materials evolve, and as confidence increases in these materials. Together, thermoset and thermoplastic structural composites will comprise virtually all of the volume of what may be called composite materials.

Part forming processes also are numerous and range from high worker-contact hand layup to low worker-contact resin transfer molding. Although many automated or semi-automated forming processes are available – such as filament winding, machine tape laying, braiding, and pultrusion – hand-lay operations are still quite common in the industry.

With the significant planned expansion of application and usage, there is potential that worker exposure to composite materials could increase at all levels of operation, from the laboratory through the manufacturing shop. The challenge for the future is to provide the necessary procedures and orientation that will allow actual reduction and worker exposure even though usage of these materials is dramatically increasing.

Advanced Polymer Matrix Resins & Constituents: An Overview of Manufacturing, Composition, and Handling

Dr. Melvin R. Kantz
Ferro Corporation, Composites Division

This paper examines briefly the manufacture of typical aerospace-grade polymer matrix resins and their prepregs because of virtue of being chemically reactive substances, the uncured materials present a variety of potential hazards to those who work with them. The degree and the scope of the hazard depends significantly on the particular resin system and how it is handled. Our purpose is to offer an introduction into the diversity of raw materials, how they are combined and how they are normally handled in the workplace. Others will address aspects of chemical toxicology and industrial hygiene.

Composite Technology Overview - Manufacturing

Anthony A. Faoro
General Dynamics - Fort Worth Division

General Dynamics - Fort Worth Division is a fully integrated aircraft manufacturing facility containing more than 6 million square feet of production floorspace and a workforce exceeding 27,000 employees. Within the main factory, 257,700 square feet of floor space and 390 employees are dedicated to the production of composite and bonded structures for the F-16 fighter, as well as spare parts for the F-111 bomber.

Through 1987, 496,781 pounds of pre-impregnated (prepreg) graphite/epoxy composite tape had been processed since the F-16 program began in 1975. Several other components at the Fort Worth Division are also being manufactured today from fiberglass/epoxy prepreg, fiberglass/epoxy wet layups, fiberglass/phenolic wet layups, and fiber reinforced graphite/epoxy molding compounds. The number of composite parts and variety of reinforced polymeric materials is expected to increase in the future.

The following photo essay illustrates several applications of the three main steps in composites manufacturing, and the interaction of the human element in each step. Layup (the placement of composite material onto the part mold) is illustrated by showing the fabrication of stabilizer skins and fiberglass covers. Processing or curing (the application of heat and pressure to consolidate the laminate and cross-link the matrix) is illustrated with autoclave, press and oven operations. Machining (drilling, trimming and routing of the processed laminate) is illustrated to show the assembly of stabilizer skins.

This essay is restricted to current F-16 technology and does not attempt to show every composites manufacturing method used throughout industry. These examples are presented as a starting point toward a better understanding of the fundamental steps involved in most composites manufacturing methods.

Introduction to Supportability of Advanced Composites

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Supportability of advanced composite structures is a tremendously broad subject. It includes everything from the basic design concept of the structure, to the specific materials used to manufacture it, how that particular structure meshes with other composite structures in the weapon system as a whole, and the training, technical data, repair methods, personnel and support equipment required to keep that structure functional. This paper is meant to familiarize those unacquainted with advanced composites with some basic supportabililty requirements of advanced composite repair.

Material Trends in Advanced Composites

Ms. Diana Carlin
Air Force Wright Aeronautical Laboratories
Materials Laboratory
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Composite structures have become an integral part of many military systems. From their initial use on the F-14, F-15, and F-16, an extensive amount of research has been focused on understanding these unique materials and their processing. The Materials Laboratory at the Air Force Wright Aeronautical Laboratories has continually lead the development and characterization of advanced composites from initial research and development, through advanced development and manufacturing technology. The future of composite materials offers many unique opportunities for furthering the performance of composites.

As part of the Air Force's Project Forecast II, new technology efforts are being pursued to support the development of ultra-lightweight composite aircraft that are 50% lighter than current high performance aircraft. This will require a combination of new materials technologies, with the principal focus being on high performance reinforcing fibers. New, ultra-high tensile strength carbon fibers offer great promise, but improvements will be needed in their compressive properties to fully realize their potential. Ordered polymer and molecular composite technologies will also be pursued. Ordered polymer fibers and films have demonstrated low density, high tensile strength and high modulus. Molecular composite technology offers the potential for creating a tough, self-reinforced composite that could greatly simplify future manufacturing techniques.

Toxicity of Advanced Composite Matrix Materials

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Hercules Incorporated

As we enter an age where advanced composite materials appear to be making significant inroads in many new applications, the dilemma facing many health professionals is the need to be able to make intelligent assessments of human health hazards despite having extremely limited toxicity information, if any at all, on the formulated resin matrix. With the rapidly evolving nature of these matrices, and the costs associated with comprehensive toxicity testing, one is forced to examine the hazards associated with the components of a given resin system and perform a weighted-average hazards assessment, based on known effects of the system's components and sound scientific judgement. This paper highlights the toxicity of a few of the more important components.

Perhaps half of all advanced composite resin systems are epoxy resin-based. The most widely used epoxy resins found in current advanced composites are those based on diglycidyl ether of bisphenol A. DGEBPA is not particularly toxic but, like most epoxy resins, is a skin and eye irritant and a potential dermal sensitizer. Long-term feeding and skin painting studies with DGEBPA have indicated little, if any, carcinogenic potential.

Methylene dianiline and sulfonyl dianiline are the major aromatic amine curing agents used in epoxy resin systems. Both have been shown to cause cancer in animals, but extrapolation of these findings to man is questionable.

Other resin systems of importance include the polyurethanes and urea- and phenol-formaldehyde types. The isocyanate component of uncured urethane resins (e.g., toluene diisocyanate) and formaldehyde in the U/F and P/F resins present hazards to the worker both in terms of acute toxicity (skin and eye irritants; sensitizers) and chronic effects (both linked with development of cancer in animals).

Other types of resin systems, PMR 15, bismaleimides, polycyanurates (triazines), thermoplastics, etc., are briefly reviewed, and mention is made of the hazards of several solvents used in advanced composite-materials processing.

Toxicology of Carbon Fibers

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U.S. Army
Aberdeen Proving Ground, MD

Carbon fibers are light weight high tensile strength synthetic fibers widely used for such commercial applications as sports equipment, reinforcing materials in structural composites and prosthetic devices for humans. Carbon fiber can be synthesized from polyacrylonitrile (PAN) or from petroleum pitch. PAN-based fibers are the purer, more commonly used precursor. Utilization of carbon fibers in military aircraft has increased because of the advantage of lightweight strength and smooth outer construction. As carbon fiber applications expand, so does the probability of worker exposure via inhalation and skin contact. Numerous *in vitro* and *in vivo* studies have been conducted to assess the health hazards from carbon fiber exposure. Modeling experiments based on equivalent aerodynamic diameters have demonstrated that diameter is the determinant of respirability. The limits of respirability for fibers is 3.5 µm diameter. The industry standard is 7-8 µm diameter which is outside the respirable range. Intratracheal and inhalation studies on carbon fibers and dusts have not resulted in any deleterious changes; however, in one inhalation study the aerosol generated was particulate dust and not fibers. In another subchronic inhalation study, rats were exposed to only one concentration of fibers preventing a dose-response evaluation. None of the studies adequately describe the particle size distribution. Future inhalation studies need to characterize the fibers generated in terms of equivalent aerodynamic diameter. Mutagenicity tests with extracts of pitch-based carbon fibers elicited positive results in sister chromatid exchange (SCE) and unscheduled DNA synthesis (UDS) tests and negative results in the chinese hamster ovary (CHO) and Ames tests. Extracts of PAN-based carbon fibers were negative in all these tests. Likewise, the pitch-based carbon fiber extracts produced positive results in a lifetime painting study in mice. Negative results were obtained with extracts from PAN-based carbon fibers in similar carcinogenicity testing in mice. Implant studies in rabbits, rodents, and humans have resulted in little or no significant tissue reactions. In the hamster tracheal organ culture model, graphite fibers were compared to crocidolite asbestos and no significant cellular differentiation changes occurred after 1 and 3 weeks in culture; whereas, asbestos produced significant proliferative degenerative changes. Limited epidemiologic studies of carbon fiber production workers have shown no adverse pulmonary effects except for some skin irritation. Current industrial PAN-based carbon fibers do not appear to be a significant inhalation hazard nor are they biologically active in several *in vitro* test systems. Minor skin and eye irritancy can be prevented with physical protection (goggles and gloves). Since carbon fibers can absorb contaminant chemicals, future studies should assess each situation (e.g., burn scenario) individually as to synergistic effects from chemical by-products, from the epoxy resins of the composite material, or from physical changes (reduction of diameter).

Safe Use of "Kevlar*" Aramid Fiber in Composites

Dr. Edmund A. Merriman
E.I. DuPont de Nemours & Co.

Although "Kevlar®" aramid fiber can be broken into respirable size subfibers, their low airborne concentrations and low toxicity permit Kevlar® to be used in composite manufacturing operations without undue health risk to aerospace workers.

Kevlar® aramid fiber has a unique substructure that abrading can separate into respirable size subfibers (fibrils). Because the fibrils have complex shapes and high static charge, they clump together, so airborne dust is minimized. Measured exposure levels from numerous industrial operations have not exceeded 0.3 fibrils/cc, and composite machining is typically 0.2 f/cc or less.

Toxicological testing since 1972 has shown Kevlar® to have low toxicity. Animal and human skin tests show no potential for sensitization, and low potential for irritation. Feeding tests show particles of Kevlar® have very low oral toxicity. Instillation and inhalation of respirable, nonfibrous polymer particles produced only nuisance dust reactions in the lungs of rats.

From long term fibril inhalation tests, DuPont concludes that Kevlar® poses minimal inhalation risk to man. Special techniques were necessary to generate high levels of respirable fibrils for rat inhalation testing. Short term (2 week) inhalation at doses up to 10,000 times typical maximum workplace levels produced slight lung scarring, which shrank with recovery. No permanent lung damage occurred at 1400 times workplace levels.

Two year rat inhalation at doses 500 times workplace levels produced lung tumors of a type not seen in man, and slight lung scarring.

At levels below 100 times typical work levels no permanent lung damage was seen. Long fibrils were found to clear from the lungs. No fibrils migrated from the lung to any other sites in the rats' bodies. From these results, DuPont has set an acceptable exposure limit (AEL) of 5 f/cc, 8-hour time-weighted average; DuPont recommends this limit to all users of Kevlar®.

Simple ventilation of composite machining tools and work areas is adequate to maintain shops below 0.5 f/cc. Consequently, normal attention to industrial hygiene permits Kevlar® to be used in composites manufacturing operations without undue health risk to aerospace workers.

*DuPont registered trademark.

USAF Presentation

Jon L. Konzen, M.D.
Owens/Corning Fiberglas

Fiber glass is one member of a family of products known collectively as man-made vitreous fibers because of their synthetic amorphous, glassy nature. Glass fibers will not burn, rot, or absorb moisture or odors. Fiber glass is generally supplied in two basic forms: wool-type fibers and textile (continuous filament) fibers.

Textile glass fibers, the type used in composite reinforcement, differ from the wool type in that they are die-drawn rather than spun. This manufacturing process results in a very uniform diameter for textile glass fiber products. Practically all fiber glass for composite reinforcement is greater than six microns in diameter. This diameter size fiber does not reach the deep lung areas (non-respirable fiber). Glass fibers break only into shorter fragments with the same diameter. Their diameters cannot be reduced by machining, milling or other mechanical processes.

Textile fibers destined for reinforcement applications are coated with a polyvinyl acetate-chrome chloride, polyvinyl acetate-silane, polyester-silane, or epoxy-silane size appropriate to the reinforcement application.

Exposure to glass fibers may cause mechanical irritation of the eyes, nose, and throat. A potential for skin sensitization can occur from the uncured resins and hardeners used in manufacturing the laminate. At times, this can be confused with the mechanical irritation caused by the fiber glass. Potentially dry but not cured epoxy-campatible sizing on the textile glass fiber could cause a skin sensitization reaction in the laminate fabricator. Such a reaction is rare even though it has been reported to occur.

In June, 1987, the International Agency for Research on Cancer (IARC) categorized fiber glass continuous filament as not classifiable with respect to human carcinogenicity. (Group 3). The evidence from human as well as animal studies was evaluated by IARC as insufficient to classify fiber glass continuous filament as a possible, probable, or confirmed cancer causing material. Fiber glass wool (primarily used for insulation in a variety of applications) was classified as a possible human carcinogen by IARC. (Group 2B). This classification was substantially based on experimental animal studies in which they were exposed to wool glass fibers through non-natural routes, such as injection or implantation.

Industrial Hygiene Investigations

Dr. Peter A. Breysse
University of Washington

Generalatmospheric monitoring techniques utilized to assess potential health hazards of workers exposed to occupational contaminants have, in the past and continues to be, relatively ineffective. This is especially true for complicated chemical mixtures involving resin formulations, some of which have been developed for use in composites. Exposures to mixtures of gases and vapors as well as man-made mineral fibers and particles are likely to be present in the atmosphere of various composite operations.

A number of technical difficulties are apparent. In many instances all resin by-products have not been identified, and if identified, information on toxicity may well be absent. The potential adverse affects of exposure to chemical mixtures have hardly ever been adequately assessed, nor is there universal agreement on the establishment of a standard for exposure for such mixtures. A further complicating factor deals with exposure to composite fibers and particles that have resin residues attached. There is also no doubt that interim standards for man made mineral fibers should be promulgated in the immediate future.

Additional environmental factors such as temperature, humidity, ventilation, metabolic requirements of the assigned tasks and total number of hours worked per week must be given serious consideration. Metabolic requirements and overtime work will undoubtedly have a significant impact on dose response.

Finally, any investigations conducted in an attempt to determine the source of worker symptoms must include adequate environmental and population data and the most successful of these programs are likely to occur in industries that have good labor-management relations.

Exposure Evaluation of Composite Materials with Emphasis on Cured Composite Dust

*Denis R. Bourcier, Ph.D.**
Corporate Industrial Hygiene
The Boeing Company

Composites have been used widely in numerous applications across the manufacturing industry. The resin as well as fiber composition of these materials varies with the application. Employee exposure evaluations of composites must consider such factors as the differences between product component availability under uncured vs. cured conditions, the component specific toxicity, the relative rate of transdermal penetration, and methods utilized to control employee contact or exposure. Several methods are available to determine component availability and dermal penetration characteristics.

Various monitoring techniques can be employed to predict exposure to composites. Air monitoring, surface contamination testing, biological monitoring and product analysis all produce information which may be useful in a hazard assessment. Also, *in vitro* dermal penetration testing provides valuable information on the significance of the dermal route of exposure.

We report on the implications of research conducted to supplement our information base on the potential health effects of composite materials. Dusts produced by machining cured composite have been subjected to morphological, chemical, and toxicological tests. These studies have provided information useful in estimating relative insult of dust to lung tissue. Additionally, the tests provide a method to screen various resin/fiber combinations. Data from our studies of several resin and fiber combinations suggest that differences noted in relative cytotoxicity and lung insult cannot be explained by resin or fabric type. Toxicity data for aluminum oxide, quartz and composite dusts were evaluated to estimate a mg/m^3 index threshold level for exposure to composite dust. An air concentration in the lower mg/m^3 range appears to be predictive of a threshold level. Presently used local ventilation is considered acceptable for restricting exposure to levels below the predictive threshold.

Future research in the areas of development and use of novel monitoring methods, toxicity testing and chemical dermal penetration measurements will provide useful information to health professionals performing composite exposure evaluations. Also, research should continue on combining tool design criteria with ventilation requirements for machining processes involving composite materials.

**Address to request reprints: Corporate Industrial Hygiene, The Boeing Company, P.O. Box 3707, Mailstop 6U-04, Seattle, WA 98124.*

The Development of a Threshold Limit Value

Ronald S. Ratney, PhD, CIH, Vice Chair
Chemical Agents Threshold Limit Values Committee
American Conference of Governmental Hygienists

In developing a recommended TLV, ideally one should have complete data in the following areas: 1) the identity of the material which is thought to be the cause of an adverse health effect, including contaminants and decomposition products; 2) the jobs of the exposed workers, the processes they use and demographic characteristics such as age, length of exposed employment and smoking history; 3) quantitative personal exposure measurements; and 4) the health outcome being studied and its time relationships with the presumed harmful exposure. In practice, such complete data is rarely obtained but where it is, an appropriate exposure limit is frequently clearly apparent without the use of complex mathematical risk modeling procedures. Where significant gaps in the data exist, inconsistencies between different studies are difficult or impossible to reconcile and any recommended exposure limits are of dubious validity even where sophisticated observational methods or data analyses are used. Examples in each of the above categories will be described.

Engineering and Work Practice Controls for Working with Advanced Composites

Don L. Cross
Hexcel Corporation

Neither engineering nor work practice controls should be looked upon as an exclusive remedy to exposures created by advanced composites in the workplace. Each should, however, be viewed as working in concert with the other to minimize attendant exposures and their potential.

Materials utilized in Hexcel operations create exposures in the form of dust, fibers, liquids, vapors, mists, decomposition and combustion products. Hexcel's primary focus for controlling exposures is through two basic engineering approaches: isolating or containing materials and providing ventilation. Isolation is applied for both storage and process usage of certain materials. Providing enclosures or closed systems to contain certain segments of operations is also used.

Ventilation is also utilized with the primary focus being on local exhaust. Provisions for make-up air is important to the proper functioning of all exhaust ventilation systems.

Work practices, if properly implemented, can be as or more effective than engineering controls in reducing workplace exposures. Hexcel incorporates six elements into the area of work practices: job hazard analysis, protective equipment, good hygiene practices, housekeeping, hazard communication, and emergency preparedness.

Feedback mechanisms are important to maintaining effective engineering and work practice controls. Hexcel utilizes five: periodic ventilation checks, exposure monitoring, medical surveillance, job observation by supervisor, and employee comments.

Engineering Controls and Work Practices

Mr. James A. Spencer
Director of Industrial Safety & Hygiene
Grumman Corporation

This presentation describes the engineering controls and work practices utilized in the Grumman composite parts manufacturing facility in Milledgeville, Georgia.

Included in engineering controls are air conditioning, ventilation, down draft tables, exhaust hoods, exhaust booths, point of operation vacuum systems and autoclaves.

The work practices utilized and discussed include the wearing of personal protective equipment, and the utilization of Safety Releases, Hazard Grams and Hazard Communication Standard training, as well as the control of the work process by process specifications.

The presentation concludes with a discussion of the employee exposure monitoring program at this facility, along with some representative monitoring results.

Dealing With Composites

Mr. Philip Newman
Northrop Corporation

The use of composite materials is increasing dramatically as the requirements of the customers become more demanding. What was an unusual, experimental industry ten years ago, is now a common aerospace practice that is utilized by many of the nation's aerospace companies.

Because the use of composite material is fairly new, many of the companies have been forced to develop new methods and establish new locations to deal with them. These new methods and locations have been driven by two factors: 1) The need for consistently high quality, high tolerance parts and 2) the potential toxic nature of many of the chemicals used in, or in conjunction with composites. In order to meet these requirements industry has relied heavily on computer assisted automated equipment more commonly known as robots.

To meet the strict quality control requirements, composite work is often performed in clean rooms. These clean rooms must have a high turnover of filtered, temperature controlled air. Often the only "thing" working in the clean room are robots. Where requirements to actually handle the composite material exists, the use of carefully selected personnel protective equipment is used. Permeation tests should be performed on any specific type of personnel protective equipment which is prescribed as often the materials being handled are mixtures of various solvents and other chemicals.

By using the advanced technology often associated with the composite user's requirements and the careful selection of the appropriate personnel protective equipment, it is possible to safely use even the most toxic composite materials and still meet the requirements of the customer..

Engineering Controls and Work Practices for Advanced Composite Repair

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SM-ALC/MMEP
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The advanced composites flying on today's high performance aircraft consist of a high strength/ stiffness fiber embedded in a polymeric matrix. Generic advanced composite repair procedures were discussed in *Introduction to Supportability of Advanced Composite Structures*. This paper will discuss the engineering controls and work practices involved in these repairs. The repair of these materials can be done safely, but does require the worker to wear personal protective equipment (PPE) during depaint, when grinding or sanding, and when using laminating resins or uncured preimpregnated composites (prepregs).

Industrial Ventilation Systems

Kathleen M. Paulson
Naval Energy and Environmental Support Activity

An industrial ventilation system simultaneously supplies air to and exhausts air from a workplace to control contaminants. The major goal of the mechanical system is to maintain a negative pressure in the room to prevent contaminant migration from the controlled area. The Naval Energy and Environmental Support Activity (NEESA), Occupational Safety and Health Group strives to improve Navy industrial ventilation systems in three major areas: design review, system performance/acceptance tests and system design training.

This presentation discusses the basics of system design including: replacement air distribution, balanced vs. blast gate methods for exhaust systems, enclosed vs. standard hoods, duct transitions and entries, fans, air pollution control devices and stacks. Our experience includes fiber reinforced plastics (FRP) operations. FRP systems present problems similar to composite operations since both dust and solvents are produced during fabrication and repair.

System acceptance/performance testing is a critical but often neglected part of a construction contract. The tests must be complete and the data turned over to responsible parties in both the public works, and health and safety departments. These people are responsible for annual (or more frequent) system performance tests.

The final aspect of our program at NEESA is training both mechanical designers and industrial hygienists to properly design and review industrial ventilation systems.

Crash Site Evaluation

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Recent interest in widening the use of carbon-epoxy composite material for newer types of aircraft has increased the demand for more information concerning particle release from this material. Past research has suggested more data be gathered on manufacturing techniques, as well as from incidents where this material is subject to high-impact and temperature conditions as would likely occur during an aircraft mishap.

On July 13, 1988, an AV-8B Harrier II based at the Marine Corps Air Station, Cherry Point, North Carolina suffered a systems failure and crashed a few miles from the runway in a small clearing. The regional Naval Medical Command industrial hygienist was permitted to enter the crash site in an attempt to characterize carbon fiber release during cleanup operations.

Method used was NIOSH 7400 using 25 mm cassettes with 0.8 µm MCEF filters and electrostatic extension cowls. DuPont P2500A and P2500B personal sampling pumps with a flow rate from 1.9 to 2.1 liters per minute were used for both area samples and personal samples.

Results indicated background values <0.10 f/cc consistent with previous work. Activities by cleanup personnel, including searching through debris, loading and preparing debris for removal, and manually removing parts showed fiber counts greater than the 0.2 f/cc standard indicated for asbestos, but less than the 3 f/cc level recommended for carbon fibers by the Navy Environmental Health Center.

Some cases of dermatitis, due to carbon fibers, were reported. Six workers were seen at the Occupational Health Clinic for medical surveillance. No cases of asthma, respiratory or breathing difficulties were reported by cleanup personnel.

Respiratory System Symptomatology and Pulmonary Function Testing Abnormalities in Two of Four Individuals Exposed to Fumes and Pyrolysis Debris from a Composite Aircraft

CDR Edward J. Doyle, Jr.
Naval Medical Command
San Diego, CA

Two of four men on site between 8+ and 11+ hours after an F-18 crash presented with complaints of markedly reduced exercise capacity first noticed a few days after the above exposure. A background explanation of pulmonary anatomy, pathophysiology and function testing is presented followed by the case reports. In both individuals there was an abnormality in the alveolar/arteriolar gradient. In one of the individuals there was an abnormal one second forced expiratory volume which increased by 30% back to normal over five months; a markedly reduced exercise capability vs. anticipated; and a positive histamine challenge test, a test associated with both asthma and the "reactive airway dysfunction syndrome (RADS)". The findings of the later individual were considered consistent with the severity of his complaints. Questions regarding aircraft composition that might explain such findings include:

1. Could alveolar damage have been caused by cadmium absorbed onto the pyrolyzed graphite?

2. Could the ventilatory abnormality have been a result of RADS due to inhalation of pyrolysis/ environmental irritants?

I conclude that exposure to (compound) pyrolysis debris from a high tech aircraft may result in heightened airway reactivity in certain susceptible individuals.

The very unique circumstances of the exposure presentation are stressed. Independent suggestions are made regarding personnel protection during fire fighting and fire overhaul of high tech aircraft mishaps.

Immune Dysfunction in Chemically Induced Illness: A Problem for Certain Composite Workers?

Dr. Manuel N. Cooper
The Boeing Company
Seattle, WA

Certain chemicals have long been known to produce allergic disorders of the skin and lung in laboratory animals and in human beings.

The growth of immunology as a rigorous experimental discipline within the biological sciences has provided interested communities with startling concepts and a rich, though esoteric, vocabulary. A climate for misinterpretation of tests and application of pseudoscience exists.

The classic types of serum and cellular hypersensitivity described over many decades of this century, and the last, are postulates that still must be satisfied when new hypotheses are evaluated.

One molecule of small molecular weight, formaldehyde, present in some composites, does raise immune responses in the skin, through the Type IV cellular hypersensitivity mechanism.

It has been postulated that formaldehyde raises serum antibodies that are indicative of exposure, and, further, represent objective evidence of chronic polysymptomatic illness involving several organ systems, including the digestive tract and the nervous system.

Current professional experience, as indicated by the medical literature, does not support these findings or conclusions. Also, convincing dose-response relation-ships have not been found.

The presence of chemical odor, particularly if acrid or nauseating, could be disquieting. Attention to odor ventilation, microenvironments, protective equipment and worker attitudes is important.

Workers who have been told they have life threatening illnesses due to workplace exposure may show anger, fear and hostility appropriate to their belief. This distrust may not yield until enough science has been applied, generally known, and accepted.

Occupational Health Aspects of Advanced Composite Manufacture and Use

Robert S. Larsen
Industrial Hygiene Services
and
Ellen M. Scheide
Adhesives, Coatings and Sealers Division
3M

3M describes its occupational health experiences during thirty-five years of composite manufacture and customer applications. The results of several studies conducted by 3M Laboratories on the Scotchply™ products are shared. Recommendations are made on research that would help industry better understand the health hazards of advanced composites.

In only five instances were adverse health effects reportedly associated with Scotchply™ manufacture. There were two reports of vapor overexposures attributed to hardeners no longer used in manufacture, one case of dermatitis and two cases of allergic skin reactions seemingly attributed to multifunctional epoxy resins. 3M has a medical policy of precluding personnel with histories of skin disorders and allergies from working in epoxy handling operations such as composite manufacture. There is no specialized medical surveillance program for composite personnel since standard exposure control techniques can successfully minimize exposures to epoxy resins, curatives, and fibrous reinforcements. Minimizing worker exposures to vapors and gases during coater cleanup and resin exotherms are the primary industrial hygiene concerns.

3M is not aware of specific customer health problems attributed to composites but commonly receives questions about precautions to take during handling. Customers are encouraged to avoid eye and skin contact with prepregs and properly vent material during curing and processing.

4,4' - Methylenedianiline - Industrial Hygiene Experiences

J. Lindsey Chalk
McDonnell Douglas Corporation

Within the last 14 months, numerous industrial hygiene field evaluations of 4,4'-methylenedianiline (MDA) were conducted which included about 33 air samples and 69 wipe samples. This presentation highlights the findings of seven industrial processes, discusses emergency response/cleanup, and presents some of the issues surrounding MDA that may trouble the industrial hygienist. Cutting, trimming, and lay up by hand can produce measurable airborne MDA. Ventilation controls for cutting and trimming are not straightforward, since continuous air movement can dry out the product in some cases and create a far worse dust problem. Ventilated hand tools and back draft benches are suggested as options. Air spraying MDS-containing material in a large, well ventilated spray booth can apparently result in breathing zone concentrations in the neighborhood of 5 ppb, the proposed OSHA "Action Level". In order to adequately protect a spray painter from dermal absorption of MDA, inhalation of isocyanates, and heat stress, a substantial but workable complement of personal protective gear is required. A filament winding machine can present many obstacles to proper ventilation controls, but it has been accomplished with good results. An overhead plenum with an air curtain on each side and exhaust plenums at the floor which also serve as walking surfaces are two of the distinctive features of the ventilation controls implemented. A HEPA exhaust dust enclosure for spools and rollers is another essential feature for prepreg winding. Breathing zone air samples for MDA at a well controlled filament winder have ranged from "none detected" to 0.6 ppb. Cleaning the dust enclosure presents the highest exposure potential. Wipe sampling can be of significant value as part of the hazard evaluation, though no scientific protocol for their collection or interpretation exists as yet. This presentation also outlines some proper actions to take if an uncontrolled release of MDA-containing dust occurs, including medical evaluation of the cohort with the highest risk. Ten micrograms per 100 cm^2 is presented as a possible target for "clearance" wipe samples. Finally, attention is called to some problems related to MDA hazard evaluation and control, such as r"regulated areas", metamorphoses of the hazard from tacky to dusty and from uncured to cured, wipe sampling, waste disposal, and selection of personal protective gear.

Suggested Strategies in Testing for Pulmonary Abnormalities in Personnel Who Work with Composites

CDR Edward J. Doyle, Jr.
Naval Medical Command
San Diego, CA

The Presenter's appreciation of the Navy experience with composite materials as encountered at the Navy Aviation Depot, North Island (NADEP, NI) points to two sources of potential pathological exposure: 1) respirable dust, encountered when grinding/sanding portions of the graphite epoxy laminate in aircraft, and 2) fumes/vapors which are generated when the "heat blanket" method of performing localized repairs to the core adhesives becomes excessively exothermic.

The International Association for Research on Cancer (IARC) June '87 Working Group results and other pertinent studies relative to ascribing a pathologic role for inhaled fibers relative to lung cancer, mesothelioma, and fibrotic disease are reviewed. Although little evidence exists which would allow one to infer significant toxicity, information is quite scant.

Suggestions on performing surveillance on composite workers are proposed. These recommendations are made assuming the outcome for this worker is most likely to be negative for abnormalities because of low levels of dust exposure.

Finally, a strategy towards the situational physical evaluation that is warranted when an individual is exposed to fumes/vapors in an excess exothermic reaction is outlined.

Independent Consultant Summary of Medical Evaluation of Boeing Employees Working with Composite Materials Who Have Filed Workers Compensation Claims for Illness

Dr. Patricia J. Sparks
Independent Consultant

A panel of physicians, including specialists in occupational medicine and toxicology, allergy and immunology, and psychiatry, was established to evaluate 37 Boeing workers who filed claims for illness possibly related to work with composite interior airplane parts.

Over one-third of the workers had historical symptoms or signs indicative of probable skin or respiratory tract irritation related to work with phenolic or epoxy-resin-impregnated composite materials. These symptoms are compatible with the known potential toxicity of these materials.

The majority of the workers had symptoms compatible with sensory irritation (such as a headache or mild nausea) related to work with composite materials, particularly the phenol-formaldehyde resin materials which are associated with a pungent, unpleasant odor.

There was an absence of objective findings indicative of specific organ system impairment or disease to account for most of the systemic symptoms experienced by these workers.

Seventy-three percent of workers met medical criteria for a diagnosis of anxiety (panic disorder) and depression. Most of the physical symptoms (such as headache, nausea, rapid heart beat, difficulty concentrating and remembering, fatigue, chest discomfort, irritability) are likely to have been caused by moderate to severe anxiety and depression.

Most of the workers with a diagnosis of anxiety and depression have not received adequate treatment for these disorders. If specific treatment is given, most of the workers are likely to experience significant improvement in their physical symptoms. Such treatment should focus on a return to active life, rather than withdrawal and avoidance.

It is not clear whether the high prevalence of anxiety and depression seen in these workers is due to very low-level exposure to phenol, formaldehyde or organic solvents and associated sensory irritation of the respiratory tract. It is possible that other sociological factors (such as fear, distrust, misinformation from health care providers, group interaction, attorney/media involvement, or labor-management problems) are playing a major role in producing or exacerbating these workers' symptoms. To address this concern, it is necessary to study the prevalence of anxiety and depression in a similarly-exposed group of workers and matched controls in a work place that is not "contaminated" by these other sociologic factors.

The Value of Epidemiologic Studies

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SAM/EKB
Brooks Air Force Base, TX

The ongoing Air Force Health Study, the Air Force investigation of health effects in Ranch Hand veterans exposed to Agent Orange and its contaminant TCDD, is presented as a model epidemiologic study of occupational exposure to a toxic chemical. The relationship between an exposure estimate, based on total gallons sprayed, and current TCDD body burden in 352 assayed Ranch Hands is presented and discussed. Associated bias calculations are presented.

MSDS Adequacy/Availability

Mr. Alan Leibowitz
ITT Avionics

Since they were originally required by OSHA under their shipyard standards 29CFR1915, 1916, and 1917 released in the early 1970's, Material Safety Data Sheets (MSDS) have become a cornerstone of Industrial Hygiene and Chemical Safety programs. Despite the narrow focus of the regulations requiring an MSDS they became the defacto standard format for conveying health and safety data from suppliers and manufacturers to their customers.

The growth in the use of MSDS's has raised many concerns about their availability and adequacy. Initially MSDS's were generally not available because requirements for their preparation did not have the force of law behind them in the majority of industry. Later with inclusion of requirements under Hazard Communication standards they became more plentiful but specific data sheets are still not always available.

There are many possible reasons for difficulties in obtaining an MSDS. Preparation requires a dedication of resources to search out needed information. There may still be companies which are not consistently willing to commit to this requirement and prepare an MSDS prior to processing or replacing materials for distribution. A problem may also develop where a supplier is the sole source of a material. The alternative of changing supplies to get needed information does not exist. This however is significantly less of a problem than in the past.

Of greater concern is the issue of the adequacy of information provided by an MSDS. Adequacy actually encompasses two areas. They are the accuracy of the information that the suppliers provide and the sufficiency of that data.

The volume of chemicals used by most companies requires them to accept information presented in Material Safety Data Sheets at face value. This is of critical concern where significant deficiencies exist. Proper preparation of an MSDS requires a familiarity with toxicological principles and references. In addition, while the law does not require it, the ability to conduct toxicity testing is a definite advantage in conveying hazard information.

A large manufacturer is able to retain a sufficient staff to evaluate their products and develop detailed MSDS's. This is not true of smaller suppliers whose best efforts can fall short. The inability to review data for technical merit before inclusion coupled with insufficient time to properly review all references can lead to a deficient MSDS.

There is also the problem of the limited requirements for providing information on MSDS's. OSHA requires only a search of available literature before preparing an MSDS. This is a particular problem for materials where little information has been developed by toxicological evaluation. These products include the vast majority of chemicals in the marketplace.

In general the utility of MSDS's could be significantly improved if the areas covered and technical references could be expanded. Access to specific disposal information, personal protective equipment guides, and interactive effects data would greatly enhance employee and environmental protection.

Hazard Communication and Composites

M. Patricia Hubbell
McDonnell Aircraft Company

The OSHA Hazard Communication Standard includes several basic requirements which apply to composites just like any other chemical product. The manufacturer is responsible for product evaluation, providing a Material Safety Data Sheet (MSDS), and labeling. The employer using the product must pass on the label and MSDS to the employees and train them on the hazards of the product.

Particularly with new composite materials, general employee training and the availability of MSDS's is not enough. A good practice is the preparation of a product handling requirement sheet giving specific information on using a particular composite at their facility. This handling guide can be attached to the MSDS and should provide specific information on work procedures, engineering controls to use, and personal protective equipment for each stage of the composite part fabrication.

Another good practice is to communicate in an atmosphere of openness with the composite workers. There should be a name and phone number on the product handling sheet so concerns or further questions can be directed to the right person. Listen to their concerns. Answer their questions. If the facilities, engineering controls and personal protective equipment are not adequate, push for what is needed. Involve the workers in suggesting better ways to work with the materials. Equipment does exist to minimize personnel exposure by inhalation and skin contact, although it may need to be modified for composite areas. Instruction on how and when to use this equipment is part of a good hazard communication program.

Hazard Communication - Regulatory Perspective

Ms. Jennifer Silk
Occupational Safety and Health Administration

The Hazard Communication Standard (HCS) is based on the simple premise that workers have both a need and a right to know the hazards of the chemicals they work with, as well as the measures they can use to protect themselves. Workers who have access to such information will be better able to take steps to protect themselves. Employers will be better able to design appropriate protective programs, and thus reduce employee exposures. As a result, the incidence of chemical source illnesses and injuries will decrease.

The regulator requirements which have been promulgated to accomplish this purpose will be described. Under the HCS, producers of chemicals are required to evaluate the hazards of their products, and prepare appropriate labels and material safety data sheets to convey those hazards as well as additional safety and health precautions. Users of chemicals are entitled to receive properly labeled containers and appropriate material safety data sheets when they purchase a hazardous chemical.

The HCS further requires all employers who have employees exposed to hazardous chemicals to prepare a written hazard communication program; label in-facility containers; obtain material safety data sheets and make them available to employees; and train employees to understand and use the available information.

Hazard Communication - Worker Perspective

Ms. Suzanne K. Lowman
Independent Consultant

As the representative of thousands of workers in the railroad, chemical, and aerospace industries, the International Association of Machinists and Aerospace Workers (IAM) is not unfamiliar with the range of injuries and illnesses caused by exposure to workplace hazards. Over the years, thousands of IAM members have developed such job-related diseases as asbestosis, lung cancer, dermatitis, and neurological problems. The increased use of composites in the aerospace industry and the illnesses we are seeing among hundreds of workers at certain aerospace facilities, give us serious cause for concern. Workers at some facilities have been allowed to work with new composite materials without adequate information and training and without adequate engineering controls and protective equipment. We believe that compliance with OSHA's Hazard Communication Standard is merely a starting point for employers to control employee exposures to composites. Additional steps must be taken to prevent injuries and illnesses from the use of these materials.

This presentation will attempt to answer the question of what workers want with regard to their safety and health on the job and what programs are needed to protect workers who handle composites.

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